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California Red Scale: An Economic Appraisal Of an Insect Monitoring Program

ABSTRACT

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The benefits associated with the use of sex pheromone-baited traps in a program for monitoring infestation of California red scale, *Aonidiella aurantii* (Maskell), in citrus groves were estimated and compared, by benefit-cost analysis, with the total research costs for development of the program. Benefits and costs were based on data from citrus pest control districts in the Yuma Valley of Arizona and the Coachella and San Joaquin Valleys of California. The analysis showed that, even at an interest rate of 20 percent, the benefit-cost ratio for the research project was greater than one. The ratio indicates that wise use of public funds for the California red scale project delivered monetary benefits to western citrus growers that exceeded the costs of the research.

KEYWORDS: citrus, cost analysis, integrated pest management, pesticides, pheromenes, California red scale, trapping program, visual inspection.

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CALIFORNIA RED SCALE: AN ECONOMIC APPRAISAL OF AN INSECT MONITORING PROGRAM

By R. T. Ervin, P. D. Gardner, D. S. Moreno, and J. L. Baritelle 1/

INTRODUCTION

Research has contributed to the development of agriculture as California's leading industry and still is important for maintaining the State's economy. In 1979, California's cash receipts from agriculture totaled $10.4 billion (5). That amount, nearly 10 percent of the Nation's total agricultural cash receipts, was produced by only three percent of the Nation's farms (27). Also in 1979, 32.3 million acres of California land, only about one-third of the State's total, were used in agricultural production (27). California led all States in agricultural production for the previous 32 years (5).

California's extensive agriculture along with its temperate climate attracts many pests. Because agriculture is essential to the State's economy, the battle to protect the crops from arthropod pests is continuous. Through research, scientists have developed methods of controlling those pests that include 1) biological control (introduction of predatory and parasitic organisms or pathogenic agents), 2) synthetic sex pheromone (to disrupt communication between the sexes, and to monitor or trap-out males of certain insect species), 3) improved cultural practices (strip cutting, rotating crops within a field, and destroying plant stubble after harvest), 4) chemical pesticides, and 5) host plant resistance. The combination of these methods of pest control is called integrated pest management (IPM).

1/Ervin, at the time of the study, was a graduate student and Gardner is an economist, University of California, Riverside; Moreno is a research entomologist, Agricultural Research Service, and Baritelle, agricultural economist, Economic Research Service, both of the U.S. Department of Agriculture, stationed at the University of California, Riverside 92521.

The key tools of IPM are monitoring and control action thresholds. Monitoring permits the density of pest population within a given area to be estimated. The monitoring results are then assembled into a control action threshold which compares the expected profits to certain levels of pest infestations. With this information, a decision on pest control can be intelligently made. The use of IPM, instead of relying only on scheduled spraying, enables judicious use of chemicals to achieve an acceptable level of profit.

Pesticides have become established as an integral part of the U. S. production of almost all agricultural commodities. In the United States, pesticide production 2/ increased from 0.841 to 1.609 billion pounds between 1966 and 1975 (191 percent increase)(28).

The development of insect resistance increases the costs of chemical pesticides to both industry and farmers. Industry incurs added costs from the ever present need to produce new, more effective pesticides. Farmers incur added costs from their attempts to control resistant insects with pesticides that become increasingly ineffective. As taxpayers, farmers also pay for the extra research necessary to overcome insect resistance.

Because of past heavy use of synthetic chemicals and the possibility of environmental damage caused by their introduction into the environment, IPM now is considered the most responsible form of pest control on many crops. The IPM program is highly regarded for citrus and cotton because 1) pesticide usage is reduced to between 0.33 and 0.67 of

2/Involves only synthetic organic pesticides that include insecticides, rodenticides, fungicides, fumigants, and soil conditioners.

previous usage, and chances of drift and development of resistance are decreased; 2) total pest management expenditures are minimized; 3) risk is lowered by increasing knowledge and information; 4) the difference in profit between IPM and conventional pest control is negligible; and, 5) yields can be maintained at present levels (8).

Because IPM research is important to agriculture and society, the substantial funding of IPM research throughout the United States will probably be continued by private, State, and Federal agencies. One example is the research on the control of a major citrus pest, California red scale (red scale), *Aonidiella aurantii* (Maskell).

"California red scale is the most serious of insect pests in citrus plants. As a threat to the 264,000 acres of citrus orchards in California, California red scale is of major concern because it causes damage to fruit which affects marketability and if left uncontrolled, can totally destroy the productive capacity of a grove" (3).

Red scale, a small (male ca. 0.8 and female 2.0 mm) cryptic insect, causes damage by inserting its long bristlelike mouthparts into the plant tissue of small twigs, leaves, and branches for the purpose of extracting fluid. During this process, the insect injects toxic saliva into the plant. Red scale decreases the vitality of the tree and if left unchecked, results in dead wood and infested fruit. An infested tree loses support branches throughout the red scale's active period, and both production and fruit quality decline.

In 1978 the California citrus crop, valued in excess of $245 million, was the seventh highest valued crop in the State, but red scale caused an estimated overall loss of almost $12 million (4). The potential for such high loss indicates the need for research on the control of red scale.

Since 1966 scientists of the Agricultural Research Service (ARS), United States Department of Agriculture (USDA), have studied red scale at Riverside, CA. They developed a monitoring system that enables growers to determine the location and density of scale infestations in their citrus groves. Researchers claim that "if appropriately used, the monitoring system can reduce the use of insecticides and save money by replacing the expensive visual inspection."3/

The trapping device of the monitoring system consists of the red scale sex pheromone (an attractant)4/, and a sticky card that captures males. Trapping can replace the following more costly methods of red scale detection and control: pesticide is applied only after red scale has been seen by a worker(s) who walks along and inspects rows of citrus trees; or pesticide is applied annually to large blocks of citrus acreage even if the presence of red scale has not been confirmed. Because red scale infestations often occur in isolated patches, annual block spraying can be unnecessarily expensive. With the pheromone monitoring system, infested trees can be identified, and pesticides can be restricted to infested areas. Thus, spot spraying could effectively replace widespread spraying.

As the research effort on monitoring red scale with pheromone traps enters its final stage, there are some questions as to how economically effective the monitoring system has been. The purpose of this study was to record the history of the research project and evaluate it with respect to the expected benefits of the monitoring system. For evaluation, the costs of the research were compared

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3/ Statement by Dr. Daniel S. Moreno, Research Entomologist, Boyden Entomological Laboratory at Riverside, Calif., on July 29, 1981.

4/ Pheromones are chemicals given off in extremely small quantities by one insect to influence the behavior of other members of the same species. Ways in which pheromones are used include sex attraction, assemblage, alarm, foraging, and trail following (12).

with the monetary benefits derived from use of the red scale monitoring system. The specific objectives of this study were to 1) document the adoption and use of red scale control in selected citrus regions in the western United States, and 2) conduct an economic assessment of the red scale research program, including the laboratory and field experiments.

Research Methods

The adoption and use of red scale control in selected citrus regions in the Western United States was documented primarily through personal interviews of commercial growers and managers of citrus pest control districts. Other major sources of information were newspapers, county records, and a historical review of district documents.

The red scale research program was economically assessed through cost-efficiency analysis. Although cost-efficiency analysis usually is an *a priori* examination of a proposed project, this analysis was a combination of both a hindsight view of what had occurred and a prospective view of what could occur. Cost-efficiency analysis can be applied to both past and future events with equal validity. In fact, the application to past events reduces uncertainty.

In this study, a compounded benefit-cost ratio of past events was developed by comparing the present compounded value of the benefits with the present compounded value of the costs in accordance with the following model:

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} (1+i)^{t} B_t}{\sum_{t=1}^{T} (1+i)^{t} C_t},$$

where

B = present compounded value of the benefits,

C = present compounded value of the costs,

B_t = benefits accruing from the project in year t,

C_t = costs accruing from the project in year t,

i = social discount rate (interest rate), and

T = time horizon.

The two other models that were used to determine the discounted benefit-cost ratio of future events and the internal rate of return will be defined later.

Because opinions differ about the definition of an appropriate social discount rate (9), four different rates were used in this analysis. The social discount rates of 5, 10, 15, and 20 percent per year were arbitrarily selected. As the interest rate increases, the benefit-cost ratio decreases.

One of the main guides to decisionmaking used in benefit-cost analysis is the internal rate of return (IRR). The IRR is calculated by setting the above model equal to one, thereby causing the sum of discounted values of benefits to become equal to the sum of discounted values of costs, and solving for "i." For most benefit-cost analyses, if the IRR exceeds the social discount rate, the project is considered economically acceptable and should be undertaken.

The red scale pheromone monitoring system (trapping program) is now used in many parts of California and Arizona. The areas studied are the Yuma Valley, Arizona, the Coachella Valley in Riverside County, and a portion of the San Joaquin Valley in California (fig. 1). The trapping program is used in several other citrus pest control districts, but the areas identified in figure 1 were early adoptors, have continued use of the monitoring system, and are representative of most of the areas in which the trapping system now is used. They represent about 50 percent of the citrus acreage in

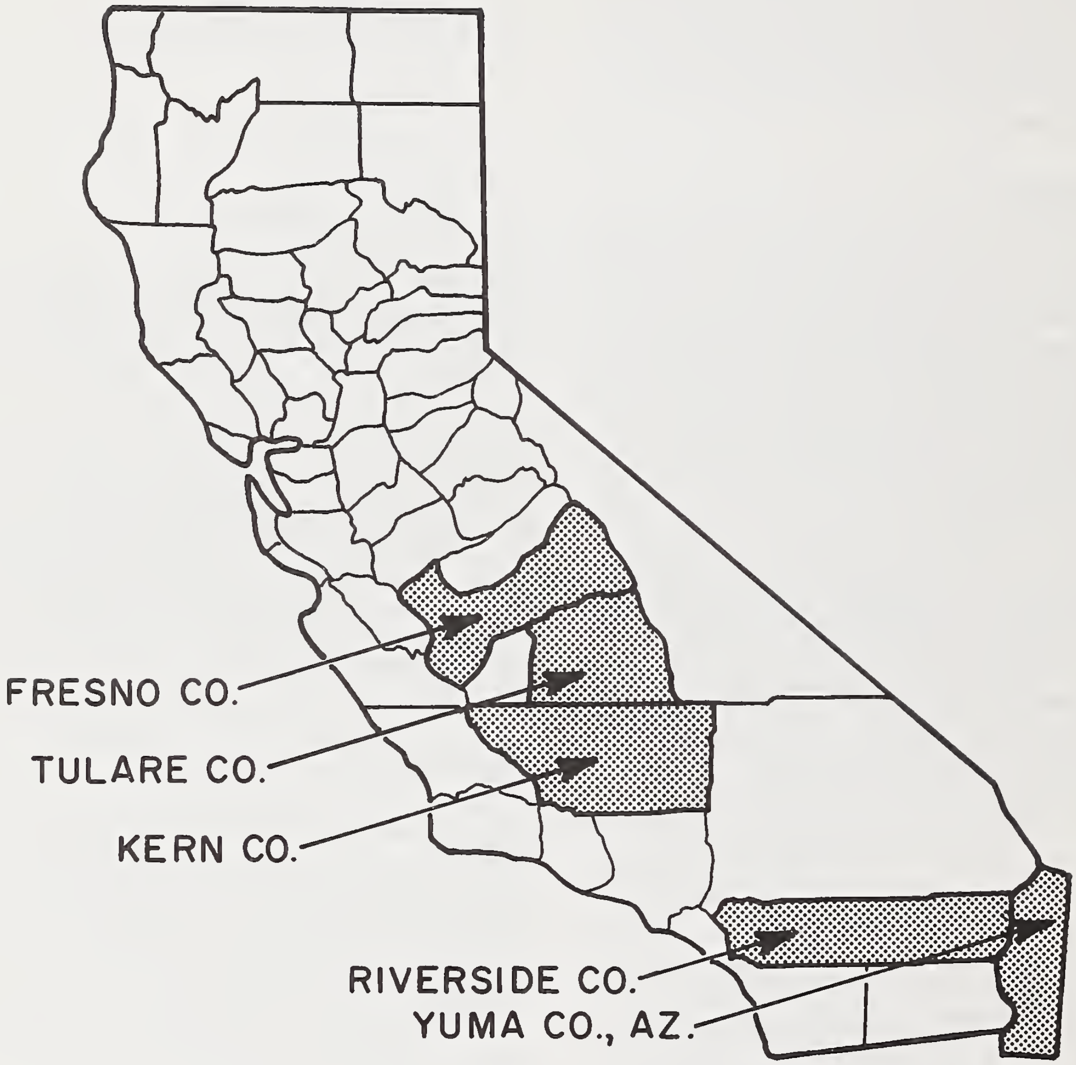

FIGURE 1. CITRUS GROWING STUDY AREAS IN CALIFORNIA AND ARIZONA

California and 40 percent in Arizona.5/

California Red Scale

Red scale's waxy covering and schedule of development make the pest difficult to control by either chemical or biological means. Chemical control of red scale is difficult for two reasons: first, the insect is sealed within a waxy scale that helps protect it from contact chemicals and provides no entrance for chemicals; and second, red scale has little opportunity to ingest pesticides because the crawlers, within a few hours after emergence, seek a place to insert their mouthparts.

For two primary reasons, red scale also is difficult to control by the introduction of natural enemies. First, only natural enemies that survive cold winters and hot, dry summers can become established and maintain continued annual control. When a high percentage of immature parasites die during the winter, the survivors may be incapable of controlling red scale in the spring. Second, red scale can be parasitized only in certain stages of its life cycle. The life cycles of the parasite and red scale should correspond favorably but often do not. For effective control, the parasite should attack the red scale at a vulnerable stage.

Biological control by two parasites, Comperiella bifasciata (Howard), and Aphytis melinus (DeBach) has been studied in citrus groves of the San Joaquin Valley. Comperiella, although well-synchronized to attack immature scales during each of their three generations, parasitized, on the average, only 60 percent of the female scales that developed during a year. That level of parasitism failed to provide satisfactory economic control(13). With 40 percent of the females still remaining in the groves, citrus growers must spray for red scale to prevent levels of cosmetic damage to the fruit that they cannot afford.

5/ This information is taken from the respective county records and compared with the State's total acreage.

Chemical treatments for red scale often affect the biological control agents. Experience showed that Comperiella tolerates considerable exposure to insecticide and in some test groves it survived spring treatments with parathion while continuing to parasitize the scale (2).

Other than in the cool coastal regions and temperate inland areas of southern California, Aphytis was unable to establish populations within a red scale infested citrus groves. Because development was poorly synchronized between Aphytis and the scale, very few scales were parasitized during spring and early summer (2). Build-up of Aphytis often was dramatic during late summer and early fall but was too late to control scale, which increased and ultimately infested the fruit. Among several factors responsible for the lag in parasitization of scale by Aphytis, the two most important are the high winter mortality of the parasite and the shortage of susceptible female scales during certain periods of late winter and spring.

The inability of Aphytis to establish a population in citrus orchards might be explained by its high susceptibility to chemical residues. Aphytis is an ectoparasitoid (a parasitoid attached to the outside of a host), and the scale's loose armor does not adequately protect this parasitoid in either its larval or adult stage. Because of harsh winters and the use of chemical pesticides, Aphytis does not establish itself as a control insect on red scale in the San Joaquin Valley or other hot inland areas.

Because the biology of red scale precludes effective control by natural means in many areas, an alternative method of control was sought.

RESEARCH DEVELOPMENT OF TRAPPING PROGRAM

Over a number of years, red scale insects for various studies have been reared in USDA entomology research laboratories at Whittier and Riverside, Calif. Since 1943, red scale had been reared on lemons and maintained on Henderson trays (11).

In 1966, Tashiro (23) described improved techniques for rearing red scale that facilitated further research on that insect.

After sex pheromones for various insects had been identified, scientists deduced that red scale also could have a sex pheromone. In 1967, Tashiro and Chambers discovered a sex pheromone, emitted by female California red scale, which elicits a copulatory response from males (24). They noted that the pheromone is continuously present in sexually mature virgin females and they can release or withhold it at will. This discovery stimulated interest in the red scale project.

In 1968, Tashiro and Moffitt reported the characteristics of red scale's mating behavior and the changes that females undergo after insemination (26). Several major factors were identified, including (1) individual males inseminated an average of 11.9 females (range, 0-30), and neither age of males (up to 4 h after emergence) nor abundance of females influenced the mating capacity; (2) females mated with a maximum of eight different males with no apparent influence on the female's reproductive potential; (3) virgin females were attractive for as long as 107 days after the crawler stage; (4) females became unattractive within 24 hours after insemination; and (5) sexual encounters were most frequent during late afternoon when males normally emerge.

In 1968, Rice and Moreno experimented on marking and recapture of red scale males for field studies (19). They had developed a trap that was baited with pheromone-producing virgin red scale females and suspended it in citrus trees. This trap, a pint ice cream carton, contained a lemon on which virgin females were attached. One end of the lemon was waxed to delay dehydration. On top of the carton was secured a sticky card to which males would become stuck. Openings were cut into the carton and covered with 160-mesh nylon screening to allow exit of the pheromone, and prevent entry of males.

In 1969, Tashiro, and others developed an instrument (olfactometer) on which they determined the response of red scale males in free flight (25). They tested the response of males to virgin females on lemons enclosed in Munger cells6/ and to pheromone extracts of virgin females placed on sand which acted as a carrier. Under laboratory conditions, they found that 1) the ratio of males attracted to either virgin females or pheromone extracts compared with males attracted to the untreated controls (lemons alone or sand alone) was about 500:1, 2) sand was a reliable carrier for presentation of the pheromone, and 3) the ratio of response to different numbers of females remained constant, regardless of the attractiveness of the pheromone.

In 1970, Rice and Moreno reported use of the trap to investigate the flight behavior of red scale males (20). They noted that the males were collected predominantly in the middle and upper parts of citrus trees rather than on the lower parts. Also, association was shown between flight and temperature. The tiny red scale males could fly at least 189 m downwind and 92 m upwind and still respond to the pheromone produced by females. In the laboratory, males were unable to fly upwind when air velocities exceeded one mile per hour. Despite their small size and fragility, red scale males are able

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6/ A Munger cell consists of two pieces of 1/4-inch plate glass. These pieces of glass are 3 x 5 inches. The bottom piece has a beveled oval hole cut in the middle to fit the side of a lemon. The lemon is placed on the nonbeveled side of the glass and sealed in place on both sides of the glass by means of crude beeswax. In the top piece of glass, a hole of 1 7/8 inch in diameter is drilled through the center. The hole is covered with a piece of 180 mesh stencil cloth. Once the top piece of glass is sealed to the bottom piece, the underside of the lemon is place in water. The water keeps the lemon turgid. The Munger cell acts as a cage to keep the female red scales, who are living on the lemon, separated from any male red scales living outside the cell.

to use very light winds when responding to the sex pheromone. Because maximum pheromone emission continues for about 15 days, and 30-70 percent of the scale females die within that period, the caged fruit with scales was replaced every other week. A minimum of 50 live virgin females was needed for adequate emission of pheromone.

In 1970, California red scale sex pheromone was finally isolated and a few of its properties were described (30). The researchers understood that this was the first chemical investigation of a sex attractant in a scale insect. They noted many similarities between the properties of known acetates and the properties of the red scale sex pheromone. The similarities, however, did not necessarily imply that the pheromone was an acetate.

Shaw and others in 1971 tested the monitoring capabilities of the trap with virgin females and the sticky card in three fields in the Coachella Valley of California (22). The fields previously had been visually inspected for red scale; two fields had been reported as positive and one as negative. The two infested fields were sprayed to eliminate red scales, and traps were placed in all three fields. The tests showed that each of the three fields was infested with red scale. The trap proved to be an effective substitute for visual inspection and a superior surveying tool.

Research continued in 1972 with Moreno's investigation of the anatomical site of pheromone production (16). When gross fragmented parts and cryostatic sections of females were offered to males, the female's pygidium was identified as the attractive area. Bioassays of dissected pygidial glands showed that they are the site of pheromone production. The internal location of the pheromone glands suggested that they might develop from ectodermal invaginations.

Field tests continued until 1975 while Moreno and Fargerlund studied the morphology and histology of red scale's pheromone glands (18). The attractancy of young and old virgin female scales to their respective males was also studied on a rotating-wheel olfactometer in scale-rearing rooms.

In 1976, Moreno's field tests showed a linear correlation between the mean number of males caught per week per trap per peak male flight and the proportion of mature fruit infested with scale at the end of the calendar year. 7/ These findings stimulated the development of a predictive model for red scale infestations. Because atmospheric and geographic conditions differ among citrus-producing regions in California and Arizona, data for the model were collected in many areas.

In 1976, Roelofs and others identified the chemical components of red scale's sex pheromone (21). That was the first identification of the sex pheromones for a homopteran species and eventually led to the commercial production of the synthetic sex pheromone. The synthetic product, which has replaced virgin females as a lure, is not only less expensive and cumbersome but also eliminates the risk of virgin females mating and being transported from damaged traps to citrus trees.

A commercial trap, with the pheromone enclosed in a rubber septum and a sticky card to collect the red scale males, became available in 1978 and was quickly accepted by citrus growers. Since its introduction, the synthetic pheromone trap has been widely used in the Yuma area of Arizona, as well as in most of California from the northern Sacramento Valley to the southern Coachella Valley. Private growers have developed versions of the commercial trap.

Moreno, in collaboration with C. E. Kennett, is correlating the catches of red scale males in pheromone traps during the year with random scale density found on twigs or fruit. This correlation is then compared with percent of infested fruit prior to harvest. The objective is to develop a model by which percent of

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7/ Moreno, D. S. and C. E. Kennett, unpublished information.

infested fruit for the entire season could be predicted from the number of red scale males trapped during certain periods. Such a model should give citrus growers the predictive advantage over red scale and enable them to accurately anticipate when spraying, if necessary, would produce maximum economic benefit. In compiling weekly catches of males, the scientists observed a trend of four flight peaks per year. Based on the male catches for each generation flight from 1973 to the present they have been able to predict, within two percent, the proportion of fruit that would be infested at the end of the calendar year from the number of males caught during the first generation flight.

Moreno sees the red scale pheromone traps as a valuable tool in the decision process of integrated pest management, with potential value not only for predicting injury levels but also for timing insecticide applications and, perhaps, for timing the release of parasitoids.

STUDY AREAS

Ervin collected pertinent background information for each citrus-growing area that was studied (6).

Riverside Citrus Pest Control District No. 2, located in the Coachella Valley of southern California, was established in 1945, 10 years after red scale was first sighted there. Because the District's boundaries engulf the valley's entire agricultural community, the chance of red scale reintroduction from bordering areas is not great. This District's efforts have kept the pest under good control but have not yet fully suppressed it. Researchers first field tested the trapping program for monitoring red scale in this District. The tests proved successful, and in 1971, this District became the first to adopt the program as a method of detection. Since then, control of red scale has improved, and total suppression within the District is expected soon. This District monitors about 2.62 acres for each trap.

Yuma County Citrus Pest Control District, located in the southwestern corner of Arizona, was established in 1962 for the control of 17 insect (including red scale) or disease pests. Because the District's boundaries engulf the valley's entire agricultural community, the chance of red scale reintroduction from bordering areas is not great. Red scale was first sighted in 1973 and was monitored by visual inspection until the virgin female traps were adopted in 1975. Since then, the District's red scale control has been extremely effective. In 1979, red scale was declared eradicated from commercial citrus orchards within the District (15). This District monitors about 10 acres for each trap.

San Joaquin Valley in central California comprises eight counties of which only three produce citrus on a large scale (greater than 5,000 acres). Red scale was first noted in 1939, but most citrus producers ignored its potential threat. During the next 22 years, five red scale control districts were organized in a land pattern that indicated the growers did not fear reintroduction from bordering areas. By 1960, red scale was well established, and the five districts combined forces to control it. The united effort was disbanded in 1967 because growers thought that red scale could not be eradicated from the valley. Today, no districts in the valley search for and control red scale. Kern County Citrus Pest Control District has a trapping program to identify red scale infestation sites, but member growers are responsible for actual control. Many growers in other counties of the valley use the trapping program to detect red scale. This pest is now considered permanent in the valley, leaving no hope for eradication. Adoption of the trapping program began in this valley in 1973, and growers, on the average, monitor about six acres for each trap.

COSTS

In this study, cost-efficiency analysis was performed on the trapping program as it was used in the three study areas. In this analysis, total cost of the program was compared with 1) benefits accrued

in study areas when the trapping program, rather than visual inspection, was applied to the same acreage and 2) savings in the use of pesticides that were attributed directly to use of the trapping program. Costs of the following functions were calculated for the analysis: (1) research, (2) trapping program, (3) visual inspection; and (4) application of chemical to control California red scale.

An appropriate analysis was developed on the basis of the following assumptions: 1) the trapping program is at least as efficient as visual inspection; 2) benefits from this program will be realized well after 1990; 3) common operational costs within the three study areas are equal; 4) effects of the trapping program on quality and quantity of citrus yield are negligible; and 5) data for 1980, except research costs that ended in 1982, can be projected to 1990. Thus, data for the period from 1966 through 1990 were analyzed.

Research Costs

Throughout the development and testing of this trapping program, yearly budget proposals were submitted to justify the cost of this research. Various sources appropriated funds to continue this work, but the USDA was the main source of support. Once the program showed promise of success, other sources began to provide funds. The California Citrus Research Board in 1977 and the University of California's Integrated Pest Management (UC-IPM) Program in 1980 supplied substantial amounts of money for the work of the red scale trapping program.

Table 1, Appendix A, lists the sources and amounts of research support for this program. Specific amounts provided by the Department were not easily defined, the funds simultaneously financed several research projects and distribution among projects was not designated. Project budgets were carefully reconstructed to identify costs.

Moreno expects the emphasis of his work to shift to another area of red scale research after 1982. He thinks that the research phase of the trapping program will be completed by that time. The total costs (in 1967 dollars) of this research project through 1982 were estimated at $2,065,651.

Trapping Program Costs

A trapping program has the following steps: (1) purchasing traps; (2) placing and removing traps from the field; and (3) reading trap cards (identifying trapped red scale males). The steps can be separated into distinct costs for the purchase of traps and the labor of handling traps. All other costs of monitoring remain constant between visual inspection and trapping.

In accordance with assumption 3, certain common operational costs were determined from data produced in one study area and then applied to the other areas. These operational costs were the annual purchase price per trap unit and the hourly rate paid to visual inspectors.

The annual purchase price per trap unit was determined by applying the appropriate consumer price index value (27) to the 1979 unit trap price paid by Riverside Citrus Pest Control District No. 2.8/ The costs represent only the synthetic sex pheromone traps, not the virgin females on lemons, and are recorded in column "T" of tables 2-4, Appendix A.

The hourly rate for visual inspectors was the average paid in the Riverside District. It is assumed that the hourly rate paid to visual inspectors equals that paid to personnel handling traps. Those data appear in column "H" of tables 2-4, Appendix A.

The costs for the trapping program varied among areas because the density of traps varied. In the Riverside District, during the trapping year 1979-80, traps were placed at an average of one trap per 2.62 acres. In this District, if no red

8/ Liston Bascon identified the 1979-80 cost at $2.12 per trap.

scales were detected during their peak flight period, only one series of traps was set into the orchards. Therefore, the costs accrued from a single trapping of the total citrus acreage in the District were considered equal to the costs of a single visual inspection of the same acreage.

According to the "Remarks" section of the 1979-80 Annual Report and Five Year Summary for the Riverside District, employees placed, picked up, and read an average of 109 traps per day. The District had a permanent crew of nine employees that year. Assuming that all employees worked eight hours per day (72 worker-hours/day) on the 109 traps, labor per trap was 0.661 worker-hours. At one trap per 2.62 acres, labor per acre was 0.252 worker-hours.

The equation used to determine the annual trapping costs for the Riverside District is:

$$C = (.252)(A)(H) + (A)(T)/(2.62)$$

where

C = total cost

A = acres

H = hourly rate paid, and

T = cost per trap unit.

The numeric values in this equation depend upon the density of traps per acre. The average cost of worker-hours per acre is represented by the 0.252 and the average number of acres per trap by 2.62 (defined from data supplied by the district manager). This equation was used to determine the trapping costs for the other areas studied by substituting the appropriate numeric values, and applying the area's annual data. At one trap per 10 acres, labor in the Yuma District was 0.066 worker-hours per acre. At one trap per 6 acres, labor in the San Joaquin Valley was 0.110 worker-hours per acre. Trapping costs did not begin to accrue until the year in which each area began to use the trapping program.

Tables 2-4, Appendix A, present the trapping costs for the areas studied.

Visual Inspection Costs

The cost of visual inspection depends upon speed of the visual inspector, total number of acres inspected, and hourly pay rate, which was assumed equal to that for trap handling. As reported, Moreno found that two workers, one walking along either side of a row of trees, could inspect an average of 10 acres per 8-hour day or 0.625 acres per worker-hour (17). The speed of visual inspectors was assigned a constant rate of 0.625 acres per worker-hour. Thus, the equation for cost of visual inspection is $C = (A)(H)/(.625)$, where A is the number of acres inspected and H is the hourly pay rate. Tables 5-7, Appendix A list the annual costs of a single visual inspection for each of the three study areas. For comparison of costs for equal acreage between visual inspection and the trapping program, initial data were for that year in which the trapping program began in each respective area. The Riverside and Yuma Districts are represented by their total citrus acreage. The San Joaquin Valley is represented by only the citrus acreage in which the trapping program has been adopted.9/

Annual Costs for Chemical Control of Red Scale

For calculating the average cost per acre for annual chemical control of red scale (includes materials and applications), the proportional use of each of the five most common chemicals was first determined and then applied to each respective cost to give an average cost of chemical control. The proportions for use of chemicals were determined first for the San Joaquin Valley and later applied as representative costs for control of red scale in the three study areas (assumption 3). The use of chemicals was similar for all study areas, but costs for the San Joaquin Valley were chosen because citrus acreage was comparatively large there. Table 8, Appendix A, lists

9/ See footnote 8, p. 7.

the annual chemical costs developed for the control of red scale.

BENEFITS

Monetary values were calculated for the following benefits that were generated when red scale in citrus was monitored by the trapping program rather than by visual inspection 1) red scale was monitored with fewer worker-hours of labor and 2) red scale was controlled by applications of insecticides to fewer acres of citrus.

Savings in Labor

In each study area, the trapping program was expected to offer potential benefits over visual inspection in the labor (worker-hours) required for monitoring red scale in citrus. By calculation of the labor costs for monitoring the designated citrus acreage in each study area by each method, the potential benefits were converted to monetary values. The differences in the calculated costs between trapping and visual inspection (potential cash savings) appear in table 1, Appendix B.

Savings in Use of Chemicals

For determining whether the method of monitoring affected the cost of red scale control, the number of acres sprayed was compared in each study area between acreages monitored by the trapping program and by visual inspection. The average number of acres sprayed, under either method of monitoring, was designated as the treatment level. High treatment levels (many acres sprayed) would represent high costs for red scale control, and low treatment levels (few acres sprayed) would represent low costs for control. On the basis of treatment level, costs for the control of red scale were calculated and compared between the trapping program and visual inspection.

Corresponding data were not available for all three study areas. Because the organizational goals and desert climates were similar for the Riverside and Yuma Districts, various aspects of their red scale control were assumed to be similar and data for Yuma were developed from the data for the Riverside District. Because the San Joaquin Valley did not have an organized goal and has different ecological conditions than those two districts, the data for this valley were developed independently.

Acres Treated Under Visual Inspection

San Joaquin Valley. Because the San Joaquin Valley had no organized control agency, the treatment level for acreage under visual inspection varied among citrus growers, who, in 1980, described two common schedules for spraying. Growers either sprayed half of their acreage every year or sprayed their total acreage every other year. Under either schedule, an average of 50 percent of the citrus acreage is sprayed annually. This treatment level appears consistent with current data in County Pesticide Use Reports produced by County Agricultural Commissioner's offices and with estimates supplied by the California Department of Food and Agriculture. Therefore, for this study, an average treatment level of 50% was assumed for citrus acreage under visual inspection.

The reason for an annual to alternating year schedule under visual inspection is not clear. Perhaps growers lack confidence in visual inspection and spray as insurance against pest outbreaks. Treatment levels for the San Joaquin study area under visual inspection appear in table 2, Appendix B.

Riverside and Yuma Districts. For these districts, the average treatment level for red scale under visual inspection was defined from data provided by the Riverside District. Because the Yuma District had been treated for red scale for only seven years (1973-1979), with only two years under visual inspection, the data were considered inadequate for a reliable average treatment level. The Riverside District, however, had a long, well documented history of red scale control and an average 0.35 percent of that District's citrus acreage was

controlled for red scale under visual inspection.

Because these two districts were similar, it was assumed that without such early use of the trapping program, red scale infestation in the Yuma District would have approximated that in the Riverside District, and it was expected that the average acreage sprayed would be about 0.35 percent. But, the average acreage sprayed would not have reached 0.35 percent of the Yuma District's acreage until an unknown date at which red scale would have become well established. Thus, the rate of annual increase in acreage that would have been sprayed under visual inspection was difficult to estimate.

The Yuma District was using traps in the third year (1975) of known red scale infestation. In 1973, after red scale had been discovered, measures for eradication were limited. In 1974 an all-out eradicative effort began. Thus, the goals of spray treatment differed between 1973 and 1974, and available data do not justify straight line extrapolation of the annual increase of acreage sprayed for red scale. In 1982 the District manager stated, "Without the traps we would easily have increased our annual treatment of acreage by at least 10 acres each year, probably more, till the pest would be well established, at which time our annual treatment of acreage would level off to a fairly constant number of acres."10/ Therefore, for this study, it was assumed that the spray treatment level would have increased at 10 acres per year. Thus, beginning in 1975, each annual treatment level was increased by 10 acres per year until 0.35 percent of the District's acreage was reached. Table 2, Appendix B, lists each study area's annual treatment levels under visual inspection.

Acres Treated Under a Trapping Program

San Joaquin Valley. Definition of treatment level for this valley was difficult because no district used the trapping program to detect red scale followed through with control measures. Kern County Citrus Pest Control District is the largest single user of traps in the valley but leaves the control of the red scale infestations identified to individual growers. When pest-control experts were asked to estimate the decrease in acres sprayed for red scale that growers could have expected if the trapping program had been substituted for visual inspection, their responses ranged from a 50 to 70 percent.11/ The lowest estimate of the experts was used to calculate the benefits of the trapping program over visual inspection that could have been realized during the years since trapping began. Benefit is realized early in the program because most trap users are pest control advisers who have been trained to use the traps and make the recommendations upon which the growers generally rely. Thus, the number of acres sprayed under visual inspection could be reduced by 50 percent immediately upon implementation of a trapping program. Therefore, without considering the cost of the trapping program, the potential savings in treatment costs attributed to a switch from visual inspection to the trapping program in the San Joaquin Valley were estimated at 50 percent. For this study area, treatment level under a trapping program was defined as 50 percent of the number of acres previously sprayed under visual inspection. The assumption was that 25 percent of the citrus acreage would have been sprayed annually under the trapping program and 50 percent would have been sprayed annually under visual inspection.

10/ Telephone conversation with Herbert McDonald, district manager of Yuma County Citrus Pest Control District, 11 May 1982.

11/ The following reductions in acres sprayed to control red scale were attributed to use of the trapping program in California: I. F. Michaels, commercial pest control expert, Fresno, 1981, 70 percent; B. Duncan, entomologist for commercial citrus growers, Bakersfield, 1980, at least 60 percent; J. Stewart, pest control adviser, Exeter, 1980, at least 50 percent; and D. S. Moreno, research entomologist, ARS, Riverside, 1980, at least 50 percent.

Riverside and Yuma Districts. The relatively successful control of red scale under the trapping program in the Riverside and Yuma Districts had been observed, and the Yuma District claimed complete red scale suppression in 1979.

The Riverside District's observed treatment levels under the trapping program (table 3, Appendix B) were much higher than the treatment levels expected under visual inspection (table 2, Appendix B), thus creating short-run extra costs rather than benefits to the District. These short-run costs to the District are reflected in table 4, Appendix B as negative values. Before adopting the trapping program, the District probably treated only heavy infestations of red scale and did not treat light and trace infestations which then produced more serious infestions the next year and prevented complete suppression. The high treatment level associated with the trap-program peaked in 1976 and then gradually decreased. In 1980, however, the treatment level was still higher than that expected under visual inspection.

The treatment level from 1981 to 1990 is expected to continue decreasing at a rate slower than that from 1976 to 1980. Liston Bascom, district manager, stated, "I expect this decreasing treatment level to slow down to between 8 to 10 acres treated less each year, till it levels off at a constant treatment rate of 20 to 30 acres annually. The potential for complete suppression is there, but I'm not sure when that might happen."12/ Therefore, for the purpose of this study, assumption was that the treatment level, under the trapping program, would continue decreasing at 8 acres (conservative) per year to a constant level of 30 acres (conservative). Table 3, Appendix B, lists each area's annual treatment levels under a trapping program.

The decreases and increases in treatment level associated with substitution of the trapping program for visual inspection are the differences between the respective values of tables 3 and 2 and are recorded in able 4, Appendix B. In the Riverside District, projected treatment level finally, in 1988, decreased to a point that would benefit growers. The acres sprayed (table 4, Appendix B) then were multiplied by their respective annual costs for red scale control (table 7, Appendix A) and converted to projected dollars saved at the lower treatment levels (table 5, Appendix B).

ECONOMIC APPRAISAL 13/

The purpose of this study was to determine the social advantages and/or disadvantages returned from the money invested in research for the development of the trapping program for monitoring red scale in citrus. In cost analysis, the measurable effects of the program were compared with the costs in dollars. For comparison at different times, costs and benefits were converted to constant 1967 dollars.

Two types of comparison were developed: First, total aggregated benefits for all regions were compared to total research costs (table 1); second, benefits generated in each study area were compared to a weighted proportion of the total research costs (table 2). The second comparison illustrated the distribution of benefits according to study area. A cost proportion for each of the three areas was established by determining the average annual acreage in each area, summing those averages, and then calculating each area's proportion of the total. Therefore, the results of the weighted analysis are sensitive to representative acreage.

12/ Bascom was interviewed March 25, 1982, at Boyden Laboratory in Riverside.

13/ The following references were used to develop the economic appraisals: Gettinger (7), Misham (14), Anderson and Settle (1), and Headley (10).

For cost-efficiency analysis of research projects, models are were developed to:

(1) determine the compounded benefit-cost ratio of past events,

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} (1+i)^{t} B_t}{\sum_{t=1}^{T} (1+i)^{t} C_t};$$

(2) predict the discounted benefit-cost ratio of future events, and

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+i)^{t}}}{\sum_{t=1}^{T} \frac{C_t}{(1+i)^{t}}},$$

(3) determine the internal rate of return by solving for i

$$0 = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+i)^{t}};$$

where

B = present discounted (or compounded) value of the benefits,

C = present discounted (or compounded) value of the costs,

B_t = benefits accruing from the project in year t,

C_t = costs accruing from the project in year t

i = social discount rate (interest rate), and

T = time horizon.

The choice of an interest rate for use in the above models can influence decisions about a project's acceptance or continuation. A project with a long-term benefit is more attractive if a low interest rate is used, whereas a high interest rate means that distant benefits are significantly discounted, favoring short-term benefits. Choosing a proper interest rate is, therefore, an important decision and requires substantial subjective judgment. For this reason, interest rates ranging from 5 to 20 percent were used to measure the sensitivity of the comparisons.

A computer program was developed to generate data from the above models. Both costs and benefits were compounded from 1966 to 1980 and discounted from 1981 to 1990. The discounted value of $1 is simply the amount that an individual is willing to pay now for the promise of $1 at the end of a preestablished period. The results of analysis of the data sets in tables 1 and 2 appear in table 3.

The ratios between total benefits and total costs (top row, table 3) exhibit the high level of benefits returned for the costs invested. At the five percent interest rate, return was $14.55 in benefits for each $1 invested in the research project. As mentioned earlier when the interest rate increases, the benefit-cost ratio decreases. Even at the highest interest rate of 20 percent, return was $5.65 in benefits for each $1 invested in the research project. The internal rate of return for this project identifies 48.4 percent as the interest rate at which total benefits would equal total costs. Both forms of analysis agree that the red scale research was a very profitable project and represents wise and efficient use of public funds.

The ratios developed by comparing each area's benefits to its proportional costs (bottom three rows, table 3) indicate that the benefits for the San Joaquin Valley would be extremely high. In that study area, where red scale was well established, predicted savings were high because the potential for decreasing control costs were high; in the other two areas, well-established red scale control districts kept control costs low. Also, it was assumed that the estimated decrease in treatment level in the San Joaquin area would begin immediately upon

acceptance of the trapping program.

Benefit-cost ratios were similar for the Yuma and Riverside Districts, but their internal rates of return (IRR) differed. Inspection of the data suggested that the IRR is directly related to and rises with the level of red scale infestation. Therefore, the potential benefits from basing the treatment level (acres sprayed) on red scale infestation monitored by the trapping program rather than by visual inspection were greater for the San Joaquin Valley, where infestation was highest, than for either of the other two study areas. Potential benefits were lowest for the Yuma study area where red scale had been eradicated.

Those benefits were attributed exclusively to use of the trapping program but undoubtedly were influenced by the efficiency of each area's collective control for red scale. Thus, the Yuma District, which was prepared to control red scale before infestation was confirmed, claimed complete suppression in 1980, had little to gain from the trapping program, and could expect the least benefits. The San Joaquin Valley, however, did not have efficient collective control and could expect the greatest benefit. Those findings from cost analyses indicate that benefits an area can expect from adoption of the trapping program depend, in part, upon that area's overall control program, with or without the use of control districts.

CONCLUSIONS

Citrus growers are the primary beneficiaries of the ARS research project that is culminating in widespread adoption of the trapping program for monitoring red scale infestation in western citrus-growing areas. As growers realize additional savings from decreased costs of labor and of chemical applications, some savings, presumably, will be passed on to consumers as lower prices for fresh citrus and citrus products. Consumers also benefit from the research in ways that cannot be assigned monetary value. Some examples are 1) higher quality of the fresh citrus marketed and 2) a decreased use of and exposure to pesticides.

Decreased use of chemicals for controlling red scale should prevent or delay the development of its resistance toward insecticides. Resistance, the development of an ability to tolerate dosages of a toxicant that would kill the majority of individuals in a normal population of the same species, is a major problem in pest control and is accentuated by cross resistance and multiple resistance.14/ Once a pest becomes resistant toward an insecticide, another insecticide must be developed, usually at great expense.

Resistance and the need for new chemicals can be avoided or delayed by (1) restricting pesticide applications to those required by the economics of the crop and losses from pest damage, (2) treating locally, rather then generally (do not treat the whole ranch if only one block has a damaging pest population), (3) using nonpersistent pesticides whenever possible, and (4) alternating insecticides from different chemical groups to delay cross resistance.

When citrus growers who had used the trapping program were asked to identity the major benefits from the program, they unanimously identified the importance of knowing when and where to spray for red scale. Growers who know when the infestation justifies treatment spray as needed rather than on a routine schedule, and thus reduce the number of pesticide applications. The trapping program answers the when and where questions of controlling red scale in citrus.

14/ Cross resistance is the protection against several related toxicants by the action of a single defense mechanism. An example of this is citrus red mite resistance to a number of organophosphate materials. Multiple resistance is the protection against several unrelated pesticides by the action of different, coexisting mechanisms. The housefly has built up resistance to many major classes of pesticides that include organophosphates, carbamates, and organochlorines.

In 1963, a report of the Agricultural Research Service (29) stated, "Until alternate methods of insect control are developed, we must continue to use insecticides to produce the quantity and quality of foods and fibers we enjoy today." The report continues by describing various techniques of pest control that were hoped to reduce the future use of insecticides. A final paragraph stated,"The attractant approach to insect control probably offers the greatest possibilities for the development of effective and highly specific ways to control key insect species."

The present analysis shows that ARS researchers used the attractant approach in the red scale project to develop a cost-effective monitoring program for the efficient management of effective and specific control of red scale in citrus.

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APPENDIX A

Table 1. Funds for red scale projected by source, 1966-82 1/

Year	USDA 2/	Calif. Citrus Research Board	UC's IPM program	Total support (dollars)
	Dollars			
1966	43,763	----	----	43,763
1967	56,111	----	----	56,111
1968	48,981	----	----	48,981
1969	28,021	----	----	28,021
1970	44,092	----	----	44,092
1971	64,029	----	----	64,029
1972	73,661	----	----	73,661
1973	88,060	----	----	88,060
1974	84,015	----	----	84,015
1975	104,330	----	----	104,330
1976	102,271	----	----	102,271
1977	156,956	25,410	----	182,366
1978	193,722	29,310	----	223,032
1979	131,268	34,784	----	166,052
1980	178,249	44,424	29,616	252,289
1981	178,249	44,424	29,616	252,289
1982	178,249	44,424	29,616	252,289
Total	1,754,027	222,776	88,848	2,065,651

1/ Converted to 1967 dollars by use of Consumer Price Index (1967=100), Agricultural Statistics 1980 (p.417).

2/ Original data were from the annual Work Reporting Units of USDA Boyden Entomological Laboratory, Riverside, Calif. Data in the table represent 48 percent of the support provided for research on "Insects of Citrus in the Southwest." The funds for this research were used by 2 entomologists. The entomologist dealing with red scale normally received 60 percent of the total funds, 80 percent of which was used on the red scale project, while 20 percent was used on other projects. Therefore, 48 percent of the total funds represents the amount used for the red scale project and provided salaries for professional staff, equipment, transportation, and administrative needs.

Table 2. Cost of program for trapping red scale in Riverside Citrus Pest Control District No. 2

Year	"A" Acreage[1/]	"H" Hourly rate paid	"T" Cost of synthetic traps[2/]	"C" Total cost[3/] of trapping	"Z" Total cost in 1967 dollars
		Dollars			
1971	18,334	2.21	1.183	18,489	22,427
1972	18,212	2.35	1.222	19,279	24,157
1973	18,300	2.61	1.300	21,116	28,105
1974	18,150	2.84	1.440	22,965	33,919
1975	17,750	3.57	1.572	26,619	42,910
1976	17,500	3.59	1.663	26,940	45,933
1977	16,200	3.83	1.770	26,580	48,243
1978	16,200	4.19	1.905	28,884	56,439
1979	16,300	4.33	2.120	30,975	67,340
1980	16,032	4.63	2.406	33,428	82,500
1981	16,032	4.63	2.406	33,428	82,500
1982	16,032	4.63	2.406	33,428	82,500
1983	16,032	4.63	2.406	33,428	82,500
1984	16,032	4.63	2.406	33,428	82,500
1985	16,032	4.63	2.406	33,428	82,500
1986	16,032	4.63	2.406	33,428	82,500
1987	16,032	4.63	2.406	33,428	82,500
1988	16,032	4.63	2.406	33,428	82,500
1989	16,032	4.63	2.406	33,428	82,500
1990	16,032	4.63	2.406	33,428	82,500

1/ Data recorded in District's annual reports.

2/ Determined by applying the appropriate consumer price index to the 1979 price.

3/ Rounded to whole dollars. Determined from the following model:
$C = (0.252)(A)(H) + (A)(T)/(2.62)$.

Table 3. Estimated costs of trapping in Yuma County Citrus Pest Control District

Year	"A" Acreage[1/]	"H" Hourly rates paid	"T" Cost of synthetic traps[2/]	"C" Total cost[3/] of trapping	"Z" Total cost in 1967 dollars
		Dollars			
1975	34,152	3.57	1.572	13,422	21,636
1976	33,192	3.59	1.663	13,391	22,832
1977	32,960	3.83	1.770	14,172	25,722
1978	31,520	4.19	1.905	14,728	28,779
1979	29,490	4.33	2.120	14,687	31,930
1980	28,000	4.63	2.406	15,300	37,760
1981	28,000	4.63	2.406	15,300	37,760
1982	28,000	4.63	2.406	15,300	37,760
1983	28,000	4.63	2.406	15,300	37,760
1984	28,000	4.63	2.406	15,300	37,760
1985	28,000	4.63	2.406	15,300	37,760
1986	28,000	4.63	2.406	15,300	37,760
1987	28,000	4.63	2.406	15,300	37,760
1988	28,000	4.63	2.406	15,300	37,760
1989	28,000	4.63	2.406	15,300	37,760
1990	28,000	4.63	2.406	15,300	37,760

1/ 80 percent of total citrus acreage in Yuma County, AZ. "Yuma County citrus pest control district contains at least 80 percent of the total citrus acreage in the county," Herb McDonald. 80 percent of acreage listed in annual Arizona Agricultural Statistics is reported in this column.

2/ Determined by applying the appropriate consumer price index to the 1979 price.

3/ Rounded to whole dollars. Determined from the following model: $C = (0.066)(A)(H) + (A)(T)/(10)$.

Table 4. Cost of trapping in the San Joaquin Valley

Year	"A" Acreage	"H" Hourly rate paid	"T" Cost of synthetic traps 1/	"C" Total cost of trapping 2/	"Z" Total cost in 1967 dollars
		Dollars			
1973	2,000 3/	2.61	1.300	1,008	1,342
1974	2,000 3/	2.84	1.440	1,105	1,632
1975	39,697 4/	3.57	1.572	25,990	41,896
1976	40,997 4/	3.59	1.663	27,553	46,978
1977	40,095 5/	3.83	1.770	28,734	52,152
1978	50,701 5/	4.19	1.905	39,485	77,154
1979	61,429 5/	4.33	2.120	50,988	110,848
1980	84,850 5/	4.63	2.406	77,275	190,715
1981	84,850	4.63	2.406	77,275	190,715
1982	84,850	4.63	2.406	77,275	190,715
1983	84,850	4.63	2.406	77,275	190,715
1984	84,850	4.63	2.406	77,275	190,715
1985	84,850	4.63	2.406	77,275	190,715
1986	84,850	4.63	2.406	77,275	190,715
1987	84,850	4.63	2.406	77,275	190,715
1988	84,850	4.63	2.406	77,275	190,715
1989	84,850	4.63	2.406	77,275	190,715
1990	84,850	4.63	2.406	77,275	190,715

1/ Determined by applying the appropriate consumer price index to the 1979 price.

2/ Rounded to whole dollars. Determined from the following model: $C = (0.110)(A)(H) + (A)(T)/(6)$.

3/ Approximate trap use by pest control advisers (PCA). Estimate provided by Rincon-Vitova Insectaries.

4/ Approximate trap use by PCA's, Michaels and Kern County Citrus Pest Control District.

5/ Approximate acreage covered by traps. Combined information from Zoecon Corporation, Michaels and Kern County Citrus Pest Control District.

Table 5. Cost of visual inspection in Riverside Citrus Pest Control District No. 2

Year	"A" (acres)	"H" Hourly rate (dollars)	"C" Total wages for visual paid inspection[1/]	"Z" Total cost in 1967 dollars
1971	18,334	2.21	64,829	78,638
1972	18,212	2.35	68,477	85,802
1973	18,300	2.61	76,421	101,716
1974	18,150	2.84	82,474	121,814
1975	17,750	3.57	101,388	163,437
1976	17,500	3.59	100,520	171,387
1977	16,200	3.83	99,274	180,182
1978	16,200	4.19	108,605	212,214
1979	16,300	4.33	112,926	245,501
1980	16,032	4.63	118,765	293,110
1981	16,032	4.63	118,765	293,110
1982	16,032	4.63	118,765	293,110
1983	16,032	4.63	118,765	293,110
1984	16,032	4.63	118,765	293,110
1985	16,032	4.63	118,765	293,110
1986	16,032	4.63	118,765	293,110
1987	16,032	4.63	118,765	293,110
1988	16,032	4.63	118,765	293,110
1989	16,032	4.63	118,765	293,110
1990	16,032	4.63	118,765	293,110

1/ Rounded to whole dollars. $C = (A)(H)/(0.625)$.

Table 6. Cost of visual inspection in Yuma County Citrus Pest Control District

Year	"A" (acres)	"H" Hourly Rates (dollars)	"C" Annual wages[1/] for visual paid inspection	"Z" Total cost in 1967 (dollars)
1975	34,152	3.57	195,076	314,463
1976	33,192	3.59	190,655	325,067
1977	32,960	3.83	201,979	366,592
1978	31,520	4.19	211,310	412,900
1979	29,490	4.33	204,307	444,163
1980	28,000	4.63	207,424	511,922
1981	28,000	4.63	207,424	511,922
1982	28,000	4.63	207,424	511,922
1983	28,000	4.63	207,424	511,922
1984	28,000	4.63	207,424	511,922
1985	28,000	4.63	207,424	511,922
1986	28,000	4.63	207,424	511,922
1987	28,000	4.63	207,424	511,922
1988	28,000	4.63	207,424	511,922
1989	28,000	4.63	207,424	511,922
1990	28,000	4.63	207,424	511,922

1/ Rounded to whole dollars. C = (A)(H)/(0.625).

Table 7. Cost of visual inspection in the San Joaquin Valley

Year	"A" (acres)	"H" Hourly Rates (dollars)	"C" Annual wages[1/] for visual paid inspection	"Z" Total cost in 1967 dollars
1973	2,000	2.61	8,352	11,117
1974	2,000	2.84	9,088	13,423
1975	39,697	3.57	226,749	365,520
1976	40,997	3.59	235,487	401,505
1977	40,095	3.83	245,702	445,949
1978	50,701	4.19	339,900	664,169
1979	61,429	4.33	425,580	925,211
1980	84,850	4.63	628,569	1,551,308
1981	84,850	4.63	628,569	1,551,308
1982	84,850	4.63	628,569	1,551,308
1983	84,850	4.63	628,569	1,551,308
1984	84,850	4.63	628,569	1,551,308
1985	84,850	4.63	628,569	1,551,308
1986	84,850	4.63	628,569	1,551,308
1987	84,850	4.63	628,569	1,551,308
1988	84,850	4.63	628,569	1,551,308
1989	84,850	4.63	628,569	1,551,308
1990	84,850	4.63	628,569	1,551,308

1/ Rounded to whole dollars. C = (A)(H)/(0.625).

Table 8. Chemical control costs for red scale in California, 1970-80

Year	Average cost per acre	Cost in 1967 dollars
	----------- Dollars	-----------
1970	50.38	43.32
1971	55.22	45.52
1972	53.84	42.97
1973	56.29	42.29
1974	62.02	41.99
1975	69.03	42.82
1976	74.66	43.79
1977	82.80	45.62
1978	89.84	45.98
1979	103.10	47.42
1980	118.53	48.03

APPENDIX B

Table 1. Cost savings (1967 dollars)[1/] in decreased worker-hours associated with the trapping program

Year	Riverside Dist.[2/]	Yuma Dist.[3/]	San Joaquin Val[4/]	Total cost savings
1971	56,211	----	----	56,211
1972	61,645	----	----	61,645
1973	73,611	----	9,775	83,386
1974	87,895	----	11,791	99,686
1975	120,527	292,827	323,624	736,978
1976	125,454	302,235	354,527	782,216
1977	131,939	340,870	393,797	866,606
1978	155,775	384,121	587,015	1,126,911
1979	178,161	412,233	814,363	1,404,757
1980	210,610	474,162	1,360,593	2,045,365
1981	210,610	474,162	1,360,593	2,045,365
1982	210,610	474,162	1,360,593	2,045,365
1983	210,610	474,162	1,360,593	2,045,365
1984	210,610	474,162	1,360,593	2,045,365
1985	210,610	474,162	1,360,593	2,045,365
1986	210,610	474,162	1,360,593	2,045,365
1987	210,610	474,162	1,360,593	2,045,365
1988	210,610	474,162	1,360,593	2,045,365
1989	210,610	474,162	1,360,593	2,045,365
1990	210,610	474,162	1,360,593	2,045,365

1/ Savings began in the year that traps were adopted.

2/ Difference between column Z of tables 2 and 5, Appendix A.

3/ Difference between column Z of tables 3 and 6, Appendix A.

4/ Difference between column Z of tables 4 and 7, Appendix A.

Table 2 Treatment levels (number of acres sprayed with insecticide) for citrus acreage under visual inspection

Year	Riverside District 1/	Yuma District	San Joaquin Valley 2/	Total treated
		Acres		
1971	64.2	----	----	64.2
1972	63.7	----	----	63.7
1973	64.1	----	1,000.0	1,064.1
1974	63.5	----	1,000.0	1,063.5
1975	62.1	61.0	19,849.0	19,972.1
1976	61.3	71.0	20,499.0	20,631.3
1977	56.7	81.0	20,048.0	20,185.7
1978	56.7	91.0	25,351.0	25,498.7
1979	57.1	101.0	30,715.0	30,873.1
1980	56.1	98.0	42,425.0	42,579.1
1981	56.1	98.0	42,425.0	42,579.1
1982	56.1	98.0	42,425.0	42,579.1
1983	56.1	98.0	42,425.0	42,579.1
1984	56.1	98.0	42,425.0	42,579.1
1985	56.1	98.0	42,425.0	42,579.1
1986	56.1	98.0	42,425.0	42,579.1
1987	56.1	98.0	42,425.0	42,579.1
1988	56.1	98.0	42,425.0	42,579.1
1989	56.1	98.0	42,425.0	42,579.1
1990	56.1	98.0	42,425.0	42,579.1

1/ 0.35 percent of District acreage in table 2, Appendix A.

2/ 50 percent of acreage adopting trapping program in table 4, Appendix A.

Table 3. Trapping treatment level

Year	Riverside District[1/]	Yuma District[2/]	San Joaquin Valley[3/]	Total acres treated
	Acres			
1971	112.5	----	----	112.5
1972	90.6	----	----	90.6
1973	18.1	----	500.0	518.1
1974	136.2	----	500.0	636.2
1975	261.8	63	9,924.5	10,249.3
1976	319.7	79	10,249.5	10,648.2
1977	298.3	58	10,024.0	10,380.3
1978	273.7	26	12,675.5	12,975.2
1979	223.2	7	15,357.5	15,587.7
1980	112.8	Ø	21,212.5	21,328.3
1981	104.8	Ø	21,212.5	21,320.3
1982	96.8	Ø	21,212.5	21,312.3
1983	88.8	Ø	21,212.5	21,304.3
1984	80.8	Ø	21,212.5	21,296.3
1985	72.8	Ø	21,212.5	21,288.3
1986	64.8	Ø	21,212.5	21,280.3
1987	56.8	Ø	21,212.5	21,272.3
1988	48.8	Ø	21,212.5	21,264.3
1989	40.8	Ø	21,212.5	21,256.3
1990	32.8	Ø	21,212.5	21,248.3

1/ Source: District manager.

2/ Source: District manager.

3/ 50 percent of acreage listed in table 4, Appendix A.

Table 4. Decrease in chemical application (acres)[1/]

Year	Riverside District	Yuma District	San Joaquin Valley	Total acres decreased
1971	-48.3	----	----	-48.3
1972	-26.9	----	----	-26.9
1973	46.0	----	500.0	546.0
1974	-72.7	----	500.0	427.3
1975	-199.7	-2.0	9,924.5	9,722.8
1976	-258.4	-7.0	10,249.5	9,984.1
1977	-241.6	23.0	10,024.0	9,805.4
1978	-217.0	65.0	12,675.5	12,523.5
1979	-166.1	94.0	15,357.5	15,285.4
1980	-56.7	98.0	21,212.5	21,253.8
1981	-48.7	98.0	21,212.5	21,261.8
1982	-40.1	98.0	21,212.5	21,270.4
1983	-32.7	98.0	21,212.5	21,277.8
1984	-24.7	98.0	21,212.5	21,285.8
1985	-16.7	98.0	21,212.5	21,293.8
1986	-8.7	98.0	21,212.5	21,301.8
1987	-0.7	98.0	21,212.5	21,309.8
1988	7.3	98.0	21,212.5	21,317.8
1989	15.3	98.0	21,212.5	21,325.8
1990	23.3	98.0	21,212.5	21,333.8

1/ Data are the result of subtracting the data in table 3 from data in table 2, Appendix A.

Table 5. Cost savings in decreased chemical application[1/]

Year	Riverside District	Yuma District	San Joaquin Valley	Total decrease
		Dollars		
1971	-2,199	----	----	-2,199
1972	-1,156	----	----	-1,156
1973	1,945	----	21,145	23,090
1974	-3,053	----	20,995	17,942
1975	-8,551	-86	424,967	416,330
1976	-11,315	-307	448,826	437,204
1977	-11,022	1,049	457,295	447,322
1978	-9,978	4,322	582,819	577,163
1979	-7,876	4,457	728,253	724,834
1980	-2,723	4,707	1,018,836	1,020,820
1981	-2,339	4,707	1,018,836	1,021,204
1982	-1,926	4,707	1,018,836	1,021,617
1983	-1,571	4,707	1,018,836	1,021,972
1984	-1,186	4,707	1,018,836	1,022,357
1985	-802	4,707	1,018,836	1,022,741
1986	-418	4,707	1,018,836	1,023,125
1987	-34	4,707	1,018,836	1,023,509
1988	351	4,707	1,018,836	1,023,894
1989	735	4,707	1,018,836	1,024,278
1990	1,119	4,707	1,018,836	1,024,662

1/ All data are in 1967 dollars.

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